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Sensitivity based Load Shedding Strategy for Avoiding Voltage Instability

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ABSTRACT
Distribution networks (DNs) are being operated closer to the voltage stability boundaries due to the exponentially increasing power demand. This paper presents a sensitivity based load shedding strategy for averting the occurrence of voltage instability in DNs. This method identifies the most sensitive node through evaluating the sensitivity between the voltage stability and real power demand at each node and performs load shedding at the chosen node; and repeats this process till the network enters the stable region. The method improves the bus voltage profile besides avoiding voltage collapse. The simulation results on two test systems emphasize its applicability on networks of any size.
Keywords- *distribution networks, voltage stability, voltage collapse, load shedding.*

INTRODUCTION

The present day distribution networks (DNs) are more heavily loaded than ever before to meet the exponentially-increasing power demand, thereby operating closer to voltage stability (VS) boundaries. In certain industrial areas, it is observed that under certain critical loading conditions, the distribution network suffers from voltage collapse [1]. Voltage collapse is characterized by a slow variation in system operating point due to increase in the loads in such a way that the voltage magnitude gradually decreases until a sharp accelerated change occurs [2]. In recent years, voltage stability of distribution systems have thus received great attention for both analysis and enhancement of operating conditions; and several methods that includes various indices have been suggested for assessing the VS [2]-[9].

However, when the network is operating closer to voltage instability, the prime goal is prevention of voltage collapse. If the network still remains nearer to voltage instability region even after initiating the measures such as network reconfiguration, switching capacitor banks and running distribution generation (DG) units, the load curtailment at some weak buses is the only avenue for avoiding voltage collapse. Though extensive research is in vogue for load shedding of transmission networks, [8]-[14], relatively a little work is reported for load shedding of DNs to avoid voltage collapse [15]-[17].

A new strategy involving sensitivity factors for identifying the appropriate nodes for load shedding with a view of avoiding voltage instability in DNs has been proposed in this paper. The proposed strategy (PS) has been applied on two DNs and the results have been presented.

PROPOSED STRATEGY

The PS aims to find the appropriate node locations for load shedding with a view to avoid VC in DNs. It is based on the VSI suggested in [8] for assessing the operating condition of the DN and identifying the most appropriate nodes for load shedding. The VSI, which varies between unity at no load and zero at VC point, for feeder/node-m of Fig. 1 can be written as

$$VSI_m = V_k^4 - 4\{P_{km}x_{km} - Q_{km}r_{km}\}^2 - 4\{P_{km}r_{km} + Q_{km}x_{km}\}V_k^2 \qquad (1)$$

Where

V_k : voltage magnitude at node- m

VSI_m : VSI at node- m

$r_{km} + jx_{km}$: resistance and reactance of feeder- m

$P_{km} + jQ_{km}$: real and reactive powers at the receiving end of feeder- m

$P_{L-m} + jQ_{L-m}$:real and reactive power load at node- m

Eq. (1) may be written in terms of real powers by replacing Q_{km} by $P_{km}\tan\Phi_{km}$ as,

$$VSI_m = V_k^4 - 4\{P_{km}\, x_{km} - r_{km}\, P_{km}\tan\Phi_{km}\}^2 - 4\{P_{km}\, r_{km} + x_{km}\, P_{km}\tan\Phi_{km}\}V_k^2 \qquad (2)$$

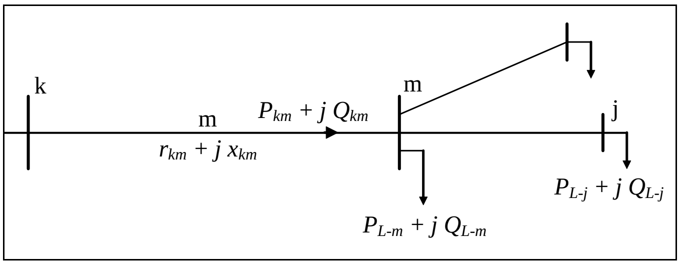

Fig. 1 Sample Distribution Feeder

The sensitivity between the VS and power flow through feeder-m can be written by

$$S_m = \frac{\Delta VSI_m}{\Delta P_{km}} = \frac{\partial VSI_m}{\partial P_{km}} = -4\left\{2P_{km}(x_{km} - r_{km}\tan\Phi_{km})^2 + V_k^2(r_{km} + x_{km}\tan\Phi_{km})\right\} \qquad (3)$$

Where

S_m : sensitivity factor relating the VS of feeder-m to the power flow through feeder-m.

ΔVSI_m : change in VSI

ΔP_{km} : change in P_{km}

Φ_{km} : power factor angle of the power at the receiving end of feeder- m

If the current operating point is nearer to voltage instability point, the load at the node possessing the largest sensitivity factor (S_m) should be shed. This shedding would improve the VS of the network. If the network still remains nearer to the voltage instability point, the sensitivity factors are again calculated after carrying out the load flow and the load should be shed at the node possessing largest sensitivity factor. This process is repeated till the network enter the secure region. The algorithmic steps are outlined below:

Read the distribution network data.

Run distribution power flow.

Compute the VSI at all the nodes using Eq. (1) and find the lowest VSI (VSI^{LOW}) in the network.

Check whether the network is away from the instability point by comparing the VSI^{LOW} with a threshold value (VSI^T). If $VSI^{LOW} > VSI^T$, the network is secure and go to step (7); else go to next step.

Evaluate the sensitivity factors for all the nodes using Eq. (3) and choose the node possessing the largest sensitivity factor.

Shed the load at the chosen node possessing largest sensitivity factor and go to step (2).

The network is stable in respect of VS. Print the results.

Stop.

Table. 1 Results of Load Shedding Strategy for 33 node Network

Load Factor	Nodes for Load Shedding	Before Load Shedding		After Load Shedding	
		VSI^{LOW}	VM^{LOW}	VSI^{LOW}	VM^{LOW}
1.00	---	0.6672	0.9038	0.6672	0.9038
1.10	20,8	0.6363	0.8931	0.6632	0.9024
1.20	20,8,28,13	0.6058	0.8822	0.6570	0.9003
1.30	20,8,28,13,17	0.5758	0.8711	0.6546	0.8995
1.40	20,8,28,13,17,29,6,31	0.5463	0.8597	0.6594	0.9011
1.50	20,8,28,13,17,29,6,31,9,10	0.5172	0.8480	0.6640	0.9027
1.60	20,8,28,13,17,29,6,31,24,9,10	0.4885	0.8360	0.6535	0.8991
1.70	20,8,28,13,17,29,6,24,31,9,10,25,22,18	0.4603	0.8237	0.6823	0.9089
1.80	20,8,28,13,17,29,6,24,25,31,9,10,22,18	0.4325	0.8110	0.6647	0.9029
1.90	20,8,28,13,17,29,6,24,25,31,9,10,22,18,30	0.4052	0.7979	0.7222	0.9219
2.00	20,8,28,13,17,29,6,24,25,9,10,31,22,18,30	0.3784	0.7843	0.7084	0.9174
2.10	20,8,28,13,17,29,6,24,25,9,10,31,22,18,30	0.3520	0.7702	0.6947	0.9130
2.20	20,8,28,13,17,29,6,24,25,22,9,10,31,18,30	0.3260	0.7556	0.6811	0.9085
2.30	20,8,28,13,17,6,29,24,25,22,9,10,31,18,30	0.3005	0.7404	0.6675	0.9039
2.40	20,8,28,13,17,6,29,24,25,22,9,10,31,18,30	0.2754	0.7244	0.6541	0.8993
2.50	20,8,28,13,17,6,29,24,25,22,9,10,31,30,18,16	0.2508	0.7077	0.6821	0.9088

Table. 2 Results of Load Shedding Strategy for 69 node Network

Load Factor	Nodes for Load Shedding	Before Load Shedding		After Load Shedding	
		VSI^{LOW}	VM^{LOW}	VSI^{LOW}	VM^{LOW}
1.00	---	0.6833	0.9092	0.6833	0.9092
1.10	---	0.6534	0.8991	0.6534	0.8991
1.20	34,35,57,41,15,14,13,65,33,10,68,58,25,12,49,64	0.6238	0.8887	0.6967	0.9136
1.30	34,35,57,41,15,14,13,65,33,10,68,58,25,12,49,64	0.5945	0.8781	0.6727	0.9056
1.40	34,35,57,41,15,14,13,65,33,10,68,25,58,12,49,64,61	0.5656	0.8672	0.8654	0.9645
1.50	34,35,57,41,15,14,13,65,33,10,68,25,58,12,49,64,61	0.5369	0.8560	0.8560	0.9619
1.60	34,35,57,41,15,14,13,33,65,10,68,25,49,12,58,64,42,61	0.5086	0.8445	0.8467	0.9592
1.70	34,35,57,41,15,14,13,33,65,10,68,49,25,12,58,64,42,61	0.4805	0.8326	0.8374	0.9566
1.80	34,35,57,41,15,14,13,33,65,10,68,49,25,12,58,64,42,61	0.4528	0.8203	0.8281	0.9539
1.90	34,35,57,41,15,14,13,33,65,10,68,49,25,12,58,64,42,61	0.4254	0.8076	0.8189	0.9513
2.00	34,35,57,41,15,14,13,33,10,65,68,49,12,25,58,64,42,61	0.3983	0.7944	0.8097	0.9486
2.10	34,35,57,41,14,15,13,33,10,65,49,68,12,25,58,64,42,61	0.3713	0.7806	0.8005	0.9459
2.20	34,35,57,41,13,14,15,33,10,65,49,68,12,25,58,64,42,7,61	0.3447	0.7663	0.7935	0.9438
2.30	34,35,57,41,13,14,15,33,10,65,49,68,12,25,58,64,42,7,6,61	0.3184	0.7512	0.7846	0.9411
2.40	34,35,57,41,13,14,15,33,10,49,65,68,12,25,58,64,42,7,6,61	0.2921	0.7352	0.7756	0.9384
2.50	34,35,57,41,33,13,14,15,10,49,68,65,12,25,58,42,64,7,6,61	0.2661	0.7183	0.7666	0.9357

SIMULATION RESULTS

The PS has been tested on 33- and 69-node DNs. The line and load data for these two networks are taken from the references [18], [19]. The power flow suggested in [20] is used in this study. The performance of the PS at different load levels has been studied through multiplying the active and reactive load powers at all nodes by a load factor that is varied in steps in the range of (1-2.5). The threshold value for VSI is taken as 0.65 for both the networks, which depends on the network configuration and the operating state. If this value is fixed too high, it does not guarantee that the network will be operated in a stable state. If this value is fixed too low, the loads to be shed will be too excessive.

The chosen nodes for load shedding by the PS for 33- and 69-node systems with different load factors are given in Table 1 and 2 respectively. The lowest value of VM (VM^{LOW}) seen in the network and VSI^{LOW}, before and after load shedding are also given in these tables for both the networks. Analysing these results, it is very clear that the PS improves the system voltage profile and brings the system far away from the region of voltage instability after load shedding. This method is suitable for DN of any size and for practical implementations.

CONCLUSIONS

A simple load shedding strategy for avoiding voltage instability has been suggested. This approach has been developed to identify the most sensitive node for load shedding. The results on 33- and 69- node DNs have clearly indicated that the PS improves voltage profile in addition to avoiding voltage instability. It also indicates that this method will be ideally suitable for practical implementation on networks of any size.

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